TESTING DGP MODIFIED GRAVITY IN THE SOLAR SYSTEM

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In this talk we review the perspectives of testing the multidimensional Dvali-Gabadadze-Porrati (DGP) model of modified gravity in the Solar System. The inner planets, contrary to the giant gaseous ones, yield the most promising scenario for the near future.

1. The DGP picture

In the Dvali-Gabadadze-Porrati (DGP) braneworld scenario[1] our Universe is a (3+1) space-time brane embedded in a five-dimensional Minkowskian bulk. All the particles and fields of our experience are constrained to remain on the brane apart from gravity which is free to explore the empty bulk. Beyond a certain threshold r_0, which is a free-parameter of the theory and is fixed by observations to ~ 5 Gigaparsec, gravity experiences strong modifications with respect to the usual four-dimensional Newton-Einstein picture: they allow to explain the observed acceleration of the expansion of the Universe without resorting to the concept of dark energy. For a recent review of the phenomenology of DGP cosmologies see Ref. 2. With more details, an intermediate regime is set by the Vainshtein scale $r_\star = (r_g r_0^2)^{1/3}$, where $r_g = 2GM/c^2$ is the Schwarzschild radius of a central object of mass M acting as source of gravitational field; G and c are the Newtonian gravitational constant and the speed of light in vacuum, respectively. For a Sun-like star $r_\star$ amounts to about 100 parsec. In the process of recovering the 4-dimensional Newton-Einstein gravity for $r << r_\star << r_0$, DGP predicts small deviations from it which yield to effects observable at local scales.[3] They come from an extra radial acceleration of the form[4–6]

$$\mathbf{a}_{\rm DGP} = \mp\left(\frac{c}{2r_0}\right)\sqrt{\frac{GM}{r}}\hat{r}. \tag{1}$$

The minus sign is related to a cosmological phase in which, in absence of cosmological constant on the brane, the Universe decelerates at late times, the Hubble parameter H tending to zero as the matter dissolves on the brane: it is called Friedmann-Lemaître-Robertson-Walker (FLRW) branch. The plus sign is related

*Fellow of the Royal Astronomical Society to a cosmological phase in which the Universe undergoes a de Sitter-like expansion with the Hubble parameter $H = c/r_0$ even in absence of matter. This is the self-accelerated branch, where the accelerated expansion of the Universe is realized without introducing a cosmological constant on the brane. Thus, there is a very important connection between local and cosmological features of gravity in the DGP model.

2. The testable effects and their measurability

About the local effects, Lue and Starkman in Ref. 5 and Iorio in Ref. 6 derived an extra-secular precession of the pericentre ω of the orbit of a test particle

$$\dot{\omega} \approx \mp \frac{3c}{8r_0}\left(1 - \frac{13}{32}e^2\right) \tag{2}$$

of 5×10^{-4} arcseconds per century ($'' \text{ cy}^{-1}$), while Iorio in Ref. 6 showed that also the mean anomaly $\mathcal{M}$ is affected by DGP gravity at a larger extent

$$\dot{\mathcal{M}} \approx \pm \frac{11c}{8r_0}\left(1 - \frac{39}{352}e^2\right); \tag{3}$$

the longitude of the ascending node Ω is left unchanged. As a result, the mean longitude $\lambda = \omega + \Omega + \mathcal{M}$, which is a widely used orbital parameter for nearly equatorial and circular orbits as those of the Solar System planets, undergoes a secular precession of the order of 10^{-3} $'' \text{ cy}^{-1}$. Such precessions are independent of the semi-major axis a of the planetary orbits and depends only on their eccentricities e via second-order terms. The effects of DGP gravity on the orbital period of a test particle were worked out by Iorio in Ref. 7; the DGP precession of a spin can be found in Ref. 8, but it is too small to be detectable in any foreseeable future.

Recent improvements in the accuracy of the data reduction process for the inner planets of the Solar System,[9,10] which can be tracked via radar-ranging, have made the possibility of testing DGP very thrilling.[6,7,11,12] In particular, Iorio in Ref. 12 showed that the recently observed secular increase of the Astronomical Unit[13,14] can be explained by the self-accelerated branch of DGP and that the predicted values of the Lue-Starkman perihelion precessions for the self-accelerated branch are compatible with the recently determined extra-perihelion advances,[10] especially for Mars, although the errors are still large. Rather surprisingly, it was recently showed in Ref. 15 that the Kuiper belt objects, if not properly modelled in the dynamical force models of the data-reduction softwares used to process planetary data, might affect the dynamics of the Earth and Mars at a non negligible level with respect to the DGP features of motion. The possibility of using the outer planets of the Solar System, suggested by Lue in Ref. 2 and, in principle, very appealing because all the compering Newtonian and Einsteinian orbital effects are smaller than the DGP precessions, is still very far from being viable.[16] Finally, we mention that it was argued[17] that the launch of a LAGEOS-like Earth artificial satellite would allow to measure the DGP perigee precession, but such a proposal was proven to be highly unfeasible in Ref. 11.

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